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INTERIM REPORT NO. 2

RESEARCH AND DEVELOPMENT
OF
CACHE MARKER SYSTEM

PHASE II: DEVELOPMENT OF ENGINEERING PROTOTYPE

Covering the Period:

15 February 1953 - 15 April 1953

Contract No [redacted]

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25 May 1953

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I. Introduction

The original proposal for Phase II of the Cache Marker System required development of engineering prototypes and evaluation of the various systems specified. Later modifications included any other systems which showed promise. On March 27, 1953, a meeting was held to discuss progress of the project with representatives of the Government and this company. At that time we were told that the need for the Cache Marker System has become most urgent. We were also asked whether we could deliver approximately 200 transponders in about six months.

To meet this new situation, efforts to find an optimum system have been curtailed. Instead, we are building a working model of a system which has demonstrated sufficient sensitivity to meet the Cache Marker System range requirements.

Upon completion of this pilot model, field tests will be performed to demonstrate the ability to accurately locate the transponder buried under the ground.

Upon successful completion of the field tests, we can proceed with manufacture of transponders. Improvement of the detection system can be carried on after the transponders are put into use.

II. Detection Systems

A brief description will be given of observations made of each of the systems investigated. The progress and problems encountered in building the pilot model will be given in detail.

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A. Crossed-Coils System

It was stated in Interim Report No. 1 that the basic difficulty with this system is the residual signal which remains after the best balance is obtained by mechanical adjustment of one coil's position with respect to the other. It was further stated that the residual signal could be minimized by introducing electrostatic shielding between the transmitter coil and the receiver coil. It was found that when shielding reduced the residual voltage by a considerable amount, the sensitivity of the system was correspondingly reduced. However, an amplifier has been built (in connection with the Q meter system which will be discussed in another part of this report) which allows one to measure small variations of amplitude of a relatively large signal. Thus, it does not appear at this time that inability to obtain a small residual signal will be serious difficulty in applying this system.

The main objection to this system, however, still remains; namely, the requirement of two coils whose orientation with respect to each other must be maintained accurately. The geometry of the crossed coils is bulky and thus undesirable from a tactical point of view. In view of the present urgency of the Cache Marker System development, no further work will be done for this system under the present task.

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III. Super-Regenerative Receiver

The super-regenerative receiver achieves extremely high sensitivity by use of an oscillatory circuit whose feed-back is controlled in a manner which causes the circuit to break in and out of oscillation at an inaudible rate. The effect of an incoming signal is to change the duration of the oscillations, thus imposing an audio modulation on the otherwise periodic pulses of oscillation. Very weak signals are capable of performing this function because of the extremely high Q of the LC circuit in the region where the circuit is on the verge of oscillating or on the verge of stopping oscillation. This circuit thus combines the function of a transmitter and a receiver when the L of the circuit is left unshielded and its field is allowed to radiate. It was thought that, because of these properties, the super-regenerative detector could be used for detection of transponders. During the time that the circuit is oscillating, circulating current is induced in the transponders which continues to "ring" after oscillation in the detector has stopped. This circulating current induces a voltage in the inductance of the detector, causing the period of oscillation to be increased.

Experiments utilizing this type of circuit were carried out. It was found that the system worked, but only for a limited distance. A range of approximately six feet was achieved. Within this range the transponder caused the detector to produce an audio signal. The intensity of this signal did not vary markedly with the changes in distance until a distance of about six feet was reached. Then the audio output stopped completely. The mechanism which causes the audio signal is not completely understood. No further development has been carried out on this system.

IV. Balanced Bridge Circuit

The impedance of a high Q parallel tuned circuit can be expressed as $Q\omega L$. Any changes which occur in the Q of the circuit will thus directly change the impedance of the circuit. On the basis of this, it was decided that an AC bridge using a parallel tuned circuit as one of the legs could be used to detect the presence of the transponders. The effect of transponder presence is described by $\frac{\omega^2 M^2}{r}$ where ω is the angular frequency, M is the mutual inductance between the tuned circuit and r is the AC resistance of the transponder. An attempt to provide such a circuit was only partially successful. It was found that, due to distributed capacity in the circuit, balance was extremely difficult to achieve. One successful experiment, however, indicated that the changes in Q were indeed appreciable and consideration of this circuit lead to the use of a Q meter circuit as a detection system.

V. Q Meter Circuit

A simple experiment was performed using the Model 160-A Boonton Q meter as a detection system. At distances of about eight feet, the change in Q as read on the Q meter due to tuning the transponder to the same frequency as the Q meter was observable. This served as the basis for a new detection system. This system has the inherent advantage of requiring only a single coil.

A Boonton Q meter consists of an oscillator, a means of coupling energy from the oscillator to supply a very small resistance (.04 ohms) with about one-half ampere of current. The voltage developed across this resistance is used to drive a series LC circuit which is tuned to resonance.

At resonance the voltage developed across the inductance is equal to Q times the voltage across the small resistance. The .04 ohms resistance prevents the low (but comparatively large) resistance of the series tuned circuit from loading the voltage source and thus varying the voltage induced in the circuit as the circuit is tuned. The voltage developed across the inductance is applied to a vacuum tube voltmeter.

An increase in sensitivity of this system can be achieved by using a tuned circuit with the highest practicable Q and as large a voltage as can be developed across a very low resistance. In order to detect small changes in the voltage developed across the inductance, an amplifier was developed which only sees the peaks of this voltage and amplifies these peaks.

The Q of the coil is given by the ratio of the voltage developed across the inductance to the voltage applied to the series resonant circuit. In the Boonton Q meter, the voltage applied to the series resonant circuit is kept constant so that the vacuum tube voltmeter can be calibrated directly in Q. The Q is equal to the ratio of the voltage developed across the inductance to the voltage applied to the series resonant circuit. The applied voltage should be as large as possible in order for a given change in Q to produce the largest change in voltage.

In order to take advantage of this fact in obtaining a more sensitive detection system, the circuit (Figure 1) which sees the voltage developed across the inductance should only be sensitive to changes in the peak voltage. This is accomplished by using a cathode follower which is biased considerably below cut-off. Thus, the only voltages that appear across the load of the cathode follower are those which extend above the

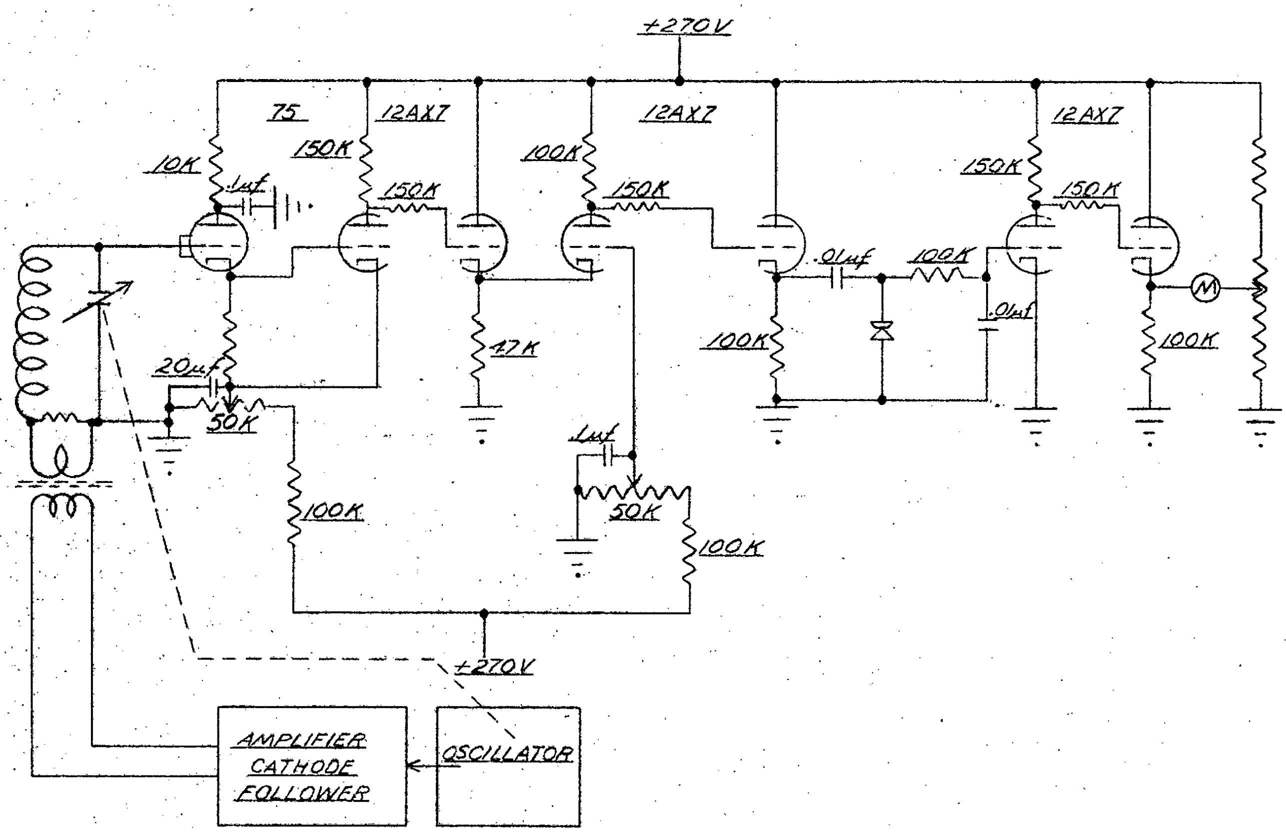

FIGURE 1. Q METER DETECTION SYSTEM

cut-off voltage, causing plate current to flow in the tube. A cathode follower is used instead of a voltage amplifier to achieve the high input impedance necessary to prevent loading of the high Q tuned circuit. In practice, in addition to the peaks of the voltage appearing across the cathode load resistance, there is a voltage due to capacitive coupling between grid and cathode. The bias on the cathode follower is adjusted so that the peaks extend above this signal. This voltage is applied to a stage of amplification direct coupled to a cathode follower and to a grounded grid amplifier. The grounded grid amplifier is biased positively so that with no signal it operates in the saturation region. The positive peaks, which have been inverted by the voltage amplifier, drive the tube out of the saturation region but remove the capacity feed-through signal because the bias is set so that only the peaks are of sufficient amplitude to bring the tube out of saturation current. These peaks are then fed to a cathode follower which are applied to a half-wave rectifier. The output of the rectifier is applied to another stage of voltage amplification, then fed to a cathode follower. An indicating meter is connected between the cathode of the output cathode follower and a voltage divider which balances out the DC signal when the system is not in the presence of a transponder. This circuit arrangement functions essentially as a window which looks only at the peaks of the signal developed across the LC circuit and amplifies small variations in these peaks. This system enables one to utilize very small variations in the voltage developed across the LC circuit.

Experiments using this detection system indicate that sufficient sensitivity is available to detect the transponder at distances of greater than 25 feet. These experiments were performed where the tuning occured in the transponder. This is obviously not the way the system has to function, but it is much easier than tuning the oscillator and the LC circuit together. In theory, at least, it should not make any difference whether the transponder is tuned or whether the detection system is tuned.

In building the pilot model of this detection system, all tuning must be accomplished in the detection system, while the resonant frequency of the transponder is fixed. This imposes a very stringent requirement on tracking between the operating frequency of the oscillator and the resonant frequency of the LC circuit. Measurements have indicated that the capacity differences can not be greater than about 0.15 micromicrofarads when the inductance of the oscillator and of the LC circuit are the same. This figure is only approximate since it is a function of the total capacity used and thus varies with frequency, being more stringent at the higher frequencies. There is no information available as yet on how close commercially available dual air capacitors can be made to track. Inquiries have been sent out to all the major manufacturers of variable air capacitors to determine whether these tolerances can be met with components now on the market.

The General Radio Company has informed us that their Type 1427-A, variable air capacitor, tracks within 2/10 of 1 per cent of the maximum capacity over a large portion of the range. This appears suitable for our requirements. However, this capacitor is not available in stock at the present time and will not be available until the latter part of September.

In order to realize the sensitivity of this system, as demonstrated experimentally by tuning the transponder, as the oscillator and LC circuit are tuned, the output must vary only very slowly as a function of frequency and preferably by a monotonic function of frequency. Any slight changes in output which occur as the system is tuned can be misread as the effect of a transponder. A false indication can, of course, always be distinguished from the effect of a transponder by changing the position of the detection system and observing the effect this has on the output of the detection system. It would be desirable, if possible, to eliminate these small variations and thus eliminate possible false indications.

Another fault of this system is the effect of hand capacity on the detection coil. The position of the operator with respect to the detection system or the position of the detection system with respect to ground changes the stray capacity of the coil, thus changing the tuning. It is possible that this can be eliminated by electrostatic shielding, but our previous experience with electrostatic shielding indicates that in minimizing hand capacity the effective sensitivity of the system is also reduced.

VI. <u>Coil Design</u>

The performance of the transponder coil as well as the coils used for the detection device has been improved greatly by using plexiglass forms in place of the previous masonite forms. The Q has been increased approximately 50 per cent.

The final design of the transponder will be determined by operational and cost considerations. As presently envisioned, the coil will be a double pie-section spider-web winding on a plastic form. The

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coil and capacity will be enclosed in a toroidal container of glass fibre reinforced plastic. Plastic coated glass fibre insulating wool will be used to support the coil within the container. The glass wool will serve as a resilient support, permitting distortion of the outer container to occur without distorting the coil.

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